Hyperons in polarized pp collisions and the origin of nucleon spin

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May 12, 2008, NSD meeting

- The strange part of nucleon spin, ΔS
- ΔS and longitudinal spin transfer of hyperons in pp, D_{LL}
- Summary and Outlook

Spin structure of nucleon

In the naive Quark Model, the nucleon is made of three quarks - p(uud), n(udd)

- The quark spins make up the nucleon spin, since the quarks are in the s-orbit:

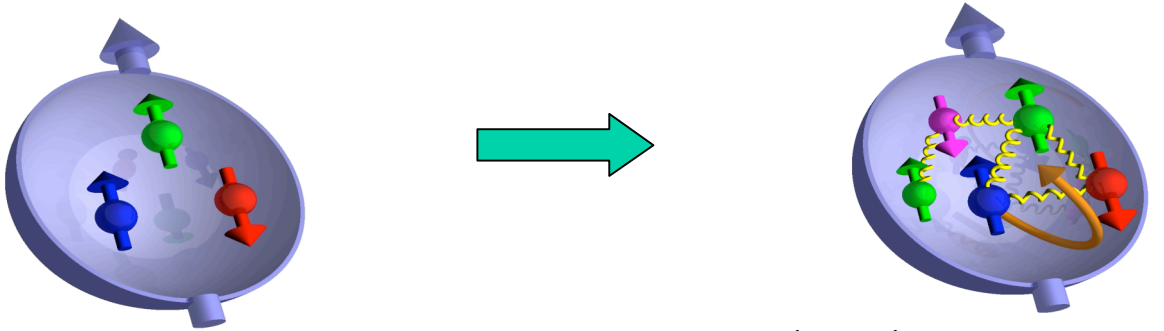
$$\Delta\Sigma = 1$$

- Ellis-Jaffe sum rule (1974) assumes strange quarks carry no net polarization, then relate $\Delta\Sigma$ to couplings in hyperons beta decay with SU(3)_f symmetry:

$$\Delta\Sigma \approx 0.6$$

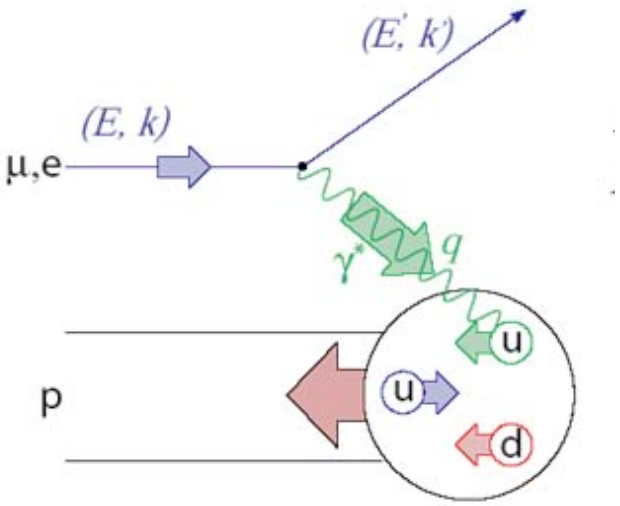
- 1988 - European Muon Collaboration (polarized DIS)
  "Spin Crisis"--- proton spin carried by quark spin is rather small: $\Delta\Sigma \sim 0.2$

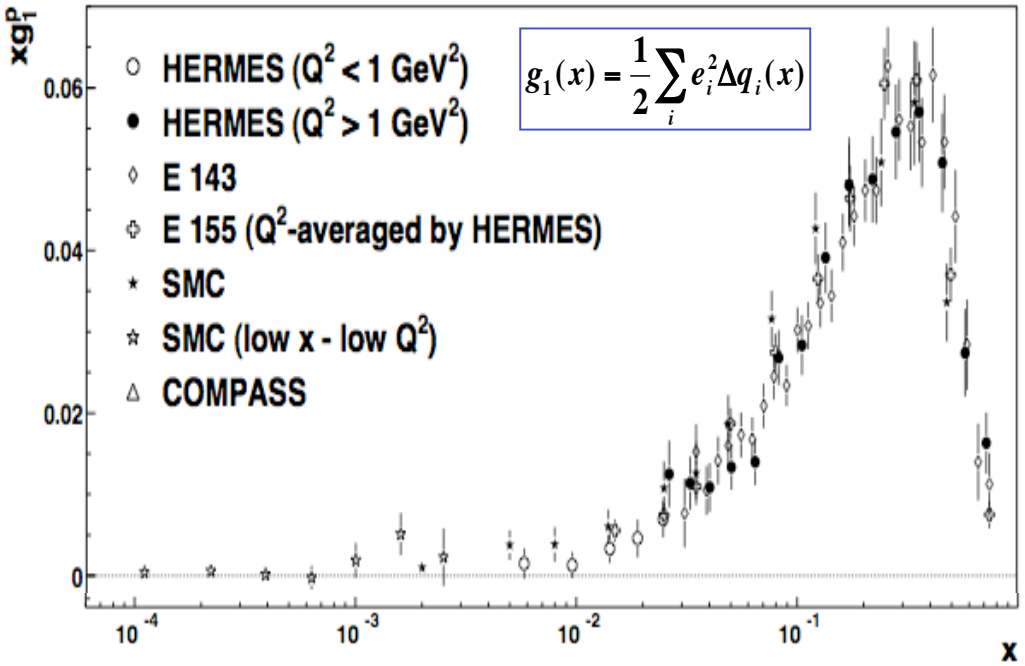
  As a result, **strange quarks** are expected to be polarized **negatively**.



$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + < L_{q,g} >$$

ΔS from polarized inclusive DIS





- How ΔS is determined in inclusive DIS?

$$\Gamma_1^p = \int_0^1 g_1^p(x)dx = \frac{1}{2}\int \sum_i e_i^2 \Delta q_i(x) = \frac{1}{18}[4\Delta U + \Delta D + \Delta S]$$

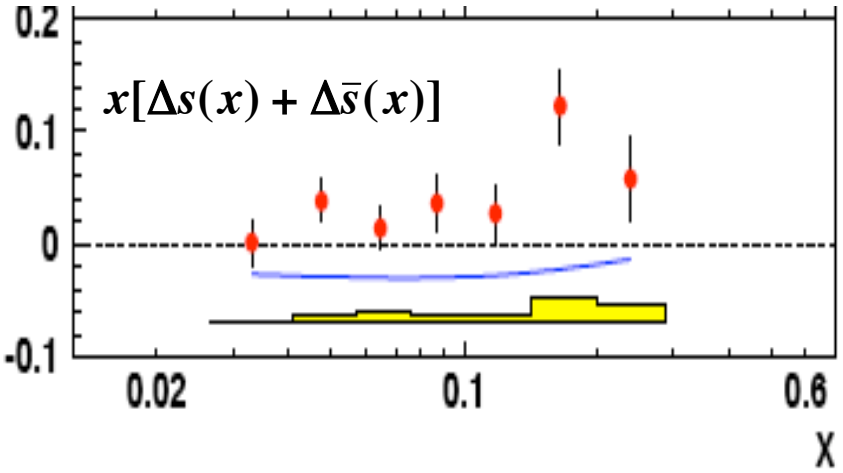
--together with neutron, hyperon β decay data using SU(3)_f symmetry,

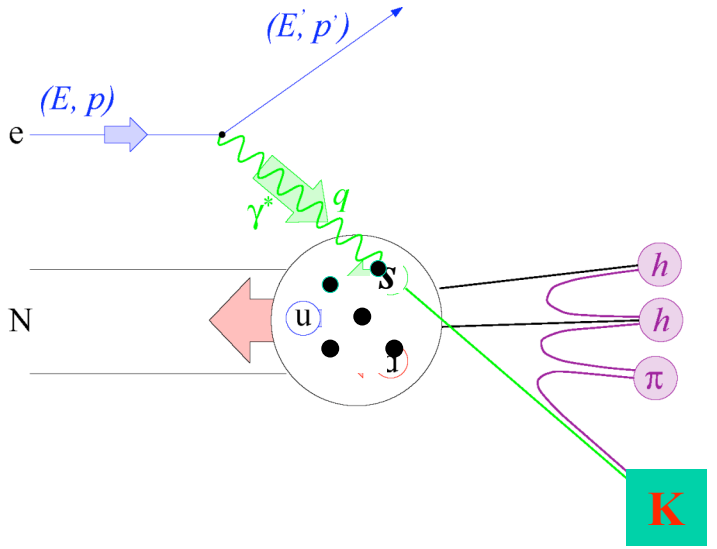
$\Rightarrow \Delta\Sigma = 0.33 \pm 0.03 \pm 0.01 \pm 0.03$: $\begin{cases} \Delta U \sim 0.84, \\ \Delta D \sim -0.43, \\ \mathbf{\Delta S \sim -0.08} \end{cases}$ (HERMES, Q^2=5 GeV^2)

ΔS from semi-inclusive DIS

- HERMES measurements in semi-inclusive DIS result in a **positive** value:

HERMES, arXiv:0803.2993





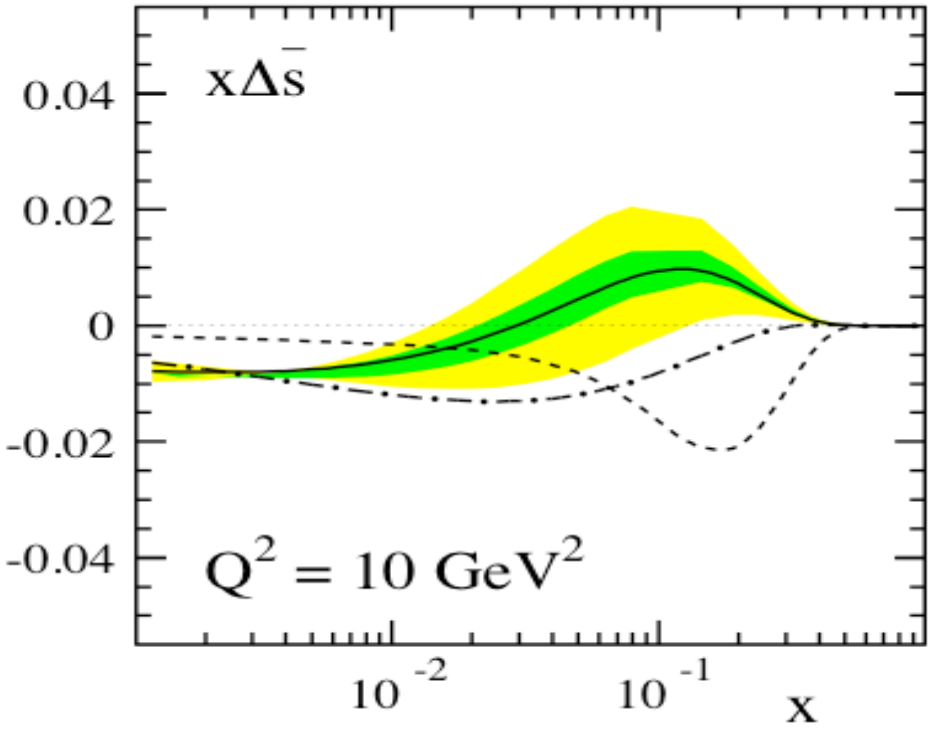
$$\Delta S' = 0.037 \pm 0.019 \pm 0.027$$

for parton fractional momenta x,
0.02<x<0.6, at a scale Q^2=2.5 GeV^2.

From global analysis

--fit all the available data in DIS, SDIS and *pp*

D. de Florian et al, arXiv:0804.0422



- First moment with best fit:

$$\Delta f = \int_0^1 \Delta f(x)dx$$

$\Delta u + \Delta\bar{u}$	0.813
$\Delta d + \Delta\bar{d}$	-0.458
$\Delta\bar{u}$	0.036
$\Delta\bar{d}$	-0.115
$\Delta\bar{s}$	-0.057
Δg	-0.084
$\Delta\Sigma$	0.242

- Clear need to measure.
- Can we do it at RHIC?

Study ΔS at RHIC with hyperons?

- Λ's contain a strange quark, whose spin is expected to carry most of the Λ spin,
- Λ polarization can be measured in experiment via weak decay

$$\frac{dN}{d\Omega} \propto 1 + \alpha (\vec{P}_\Lambda \cdot \hat{p}_p)$$

Unit vector along proton momentum in Λ's rest frame.

decay parameter 0.642 ±0.013

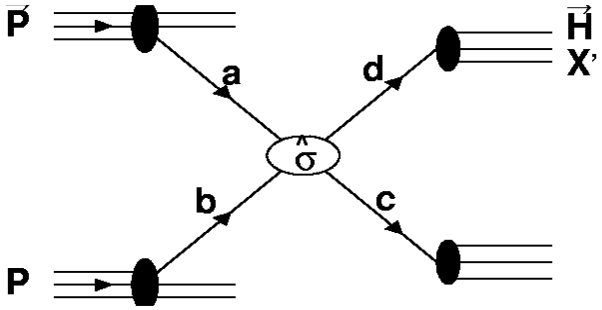
Λ polarization vector

- Can $\Lambda(\overline{\Lambda})$ polarization measurements provide sensitivity to ΔS at RHIC?

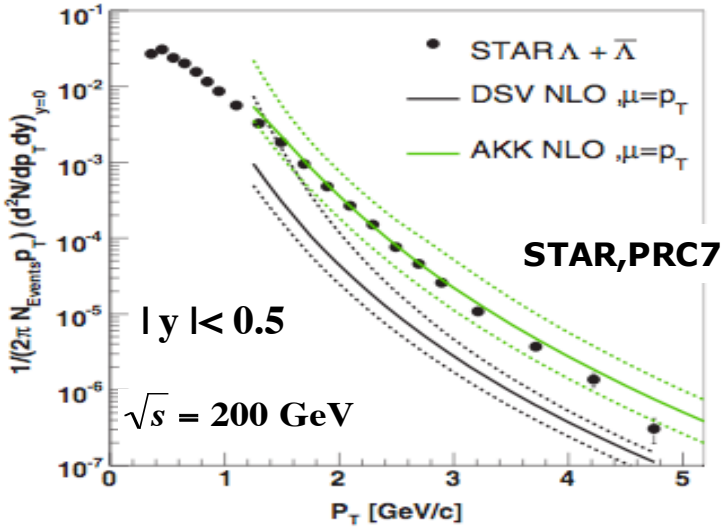
hyperon production in *pp*

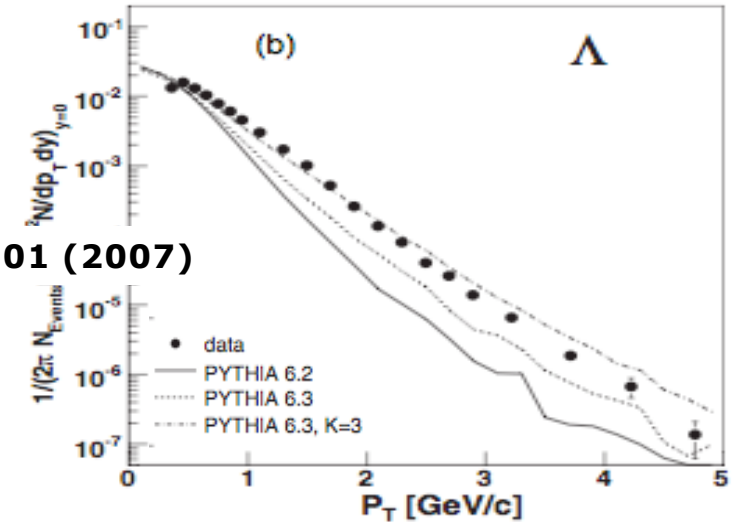
- $\Lambda(\overline{\Lambda})$ production in *pp*:

$$d\sigma \propto \int f_a(x_1) \cdot f_b(x_2) \otimes d\hat{\sigma} \otimes D^{\Lambda}(z)$$



- Data from RHIC on $\Lambda(\overline{\Lambda})$





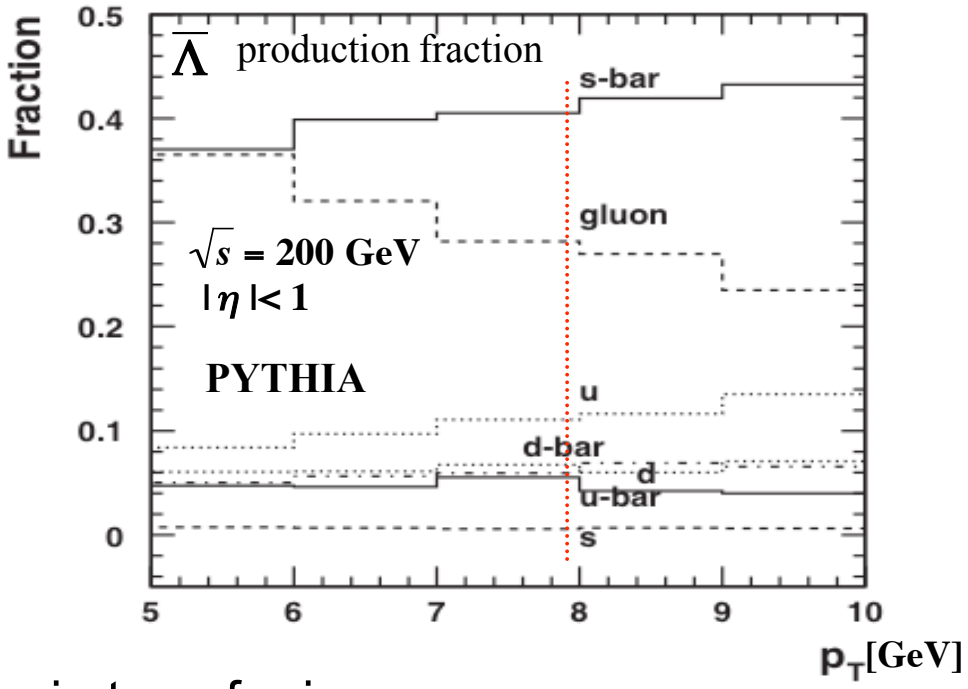
STAR,PRC75,064901 (2007)

- cross section of $\Lambda + \overline{\Lambda}$ described by pQCD from 1 to ~5 GeV.

- PYTHIA generator (LO) can also reproduce the spectra.

D_{LL}- Longitudinal spin transfer

- Production of $\bar{\Lambda}(\bar{u}\bar{d}\bar{s})$ in *pp* :



- Longitudinal spin transfer in *pp*:

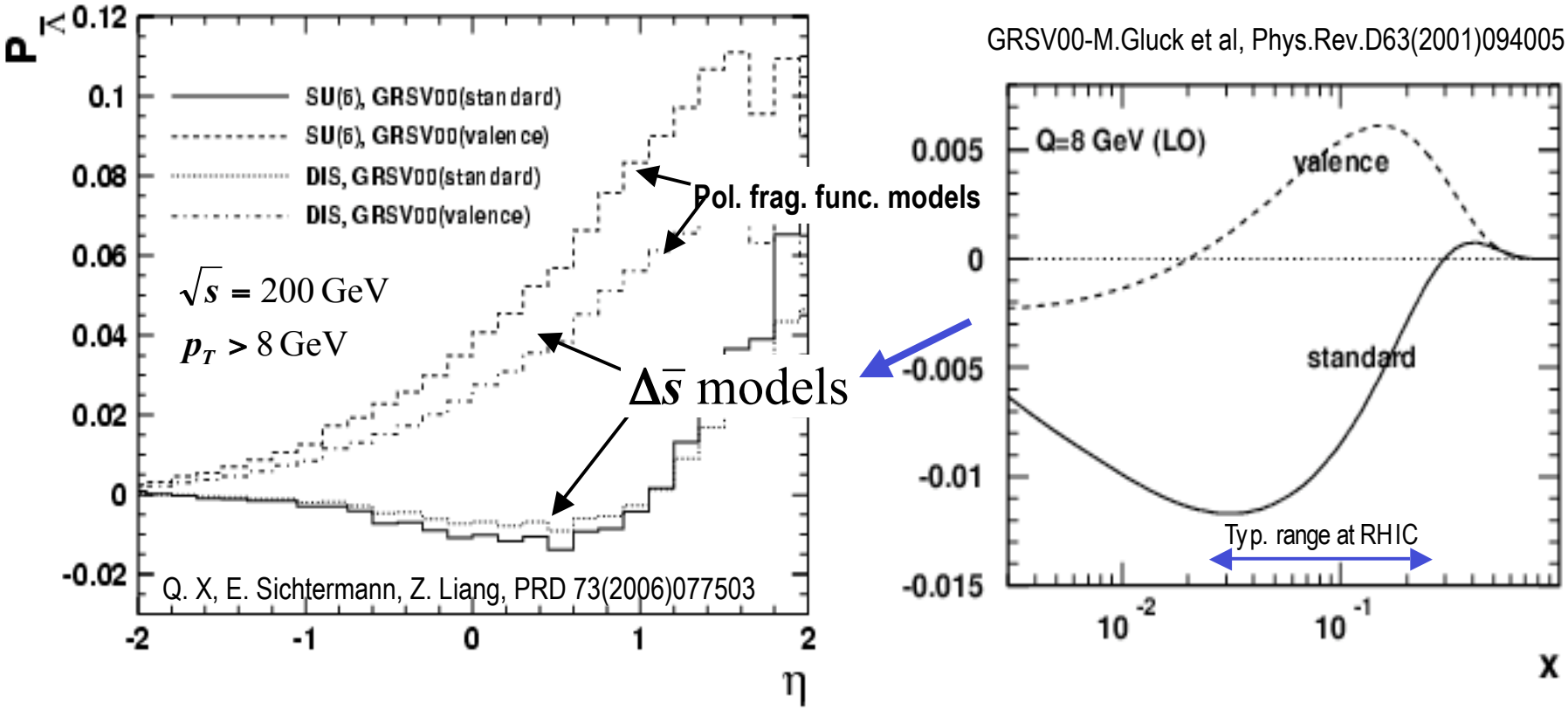
$$D_{LL} \equiv \frac{\sigma_{p^+p\to\bar{\Lambda}^+X} - \sigma_{p^+p\to\bar{\Lambda}^-X}}{\sigma_{p^+p\to\bar{\Lambda}^+X} + \sigma_{p^+p\to\bar{\Lambda}^-X}} = P_{\bar{\Lambda}}^{+}$$

$$\Delta\sigma \propto \int \underline{\Delta f_a(x_1)} \cdot f_b(x_2) \otimes d\hat{\sigma} \otimes \underline{\Delta D^{\bar{\Lambda}}(z)}$$

➡ How sensitive will anti-Lambda polarization be to $\Delta\bar{s}$?

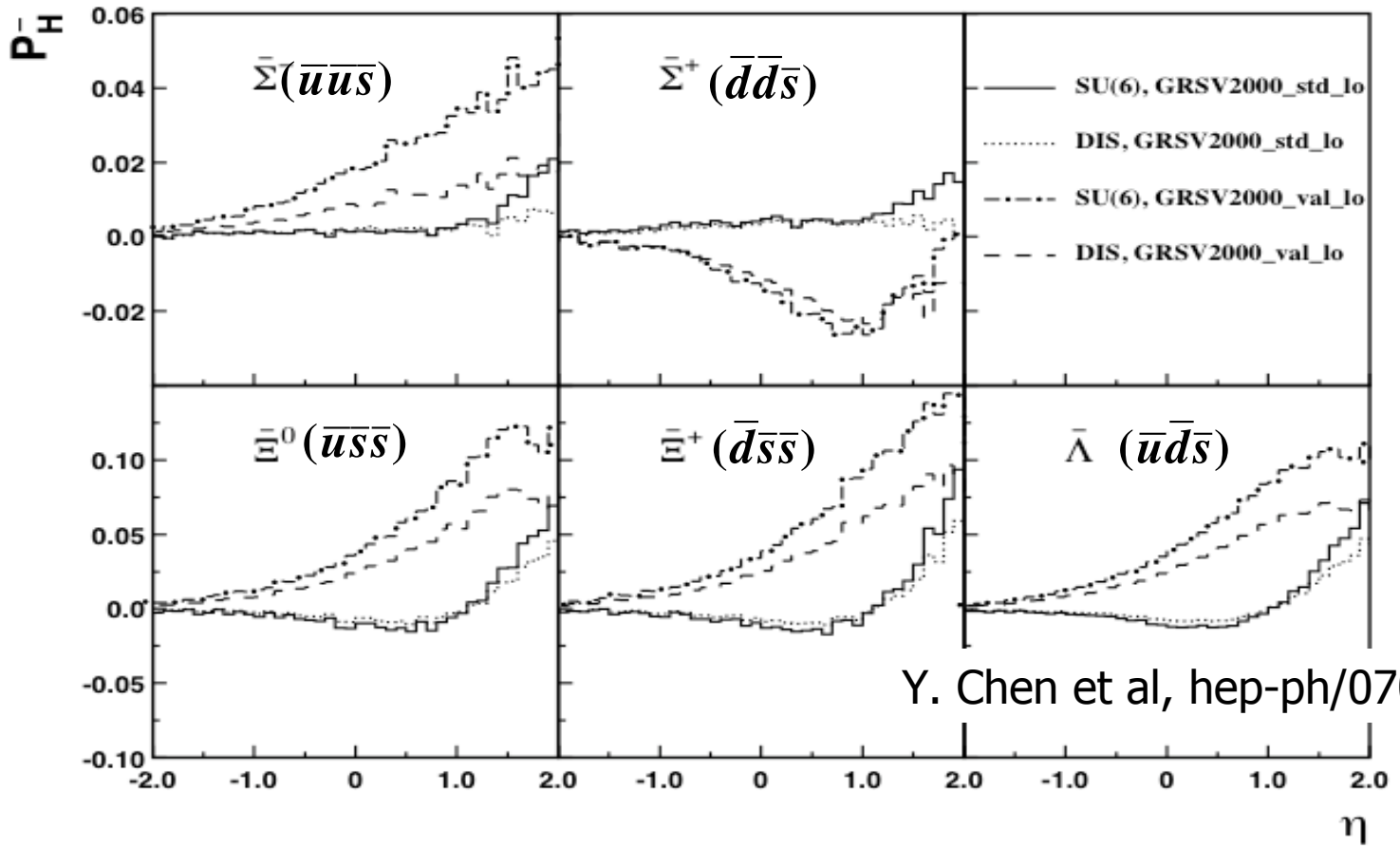
D_{LL}-Longitudinal spin transfer at RHIC

- Expectations at LO show sensitivity of D_{LL} for anti-Lambda to $\Delta\bar{s}$:



- Promising measurements---effects potentially large enough to be observed.
- D_{LL} of Λ is less sensitive to Δs, due to larger u and d quark frag. contributions.
- D_{LL} of Ξ^- should be sensitive to Δs, but need more integrated luminosity.

How about other (anti-)hyperons?



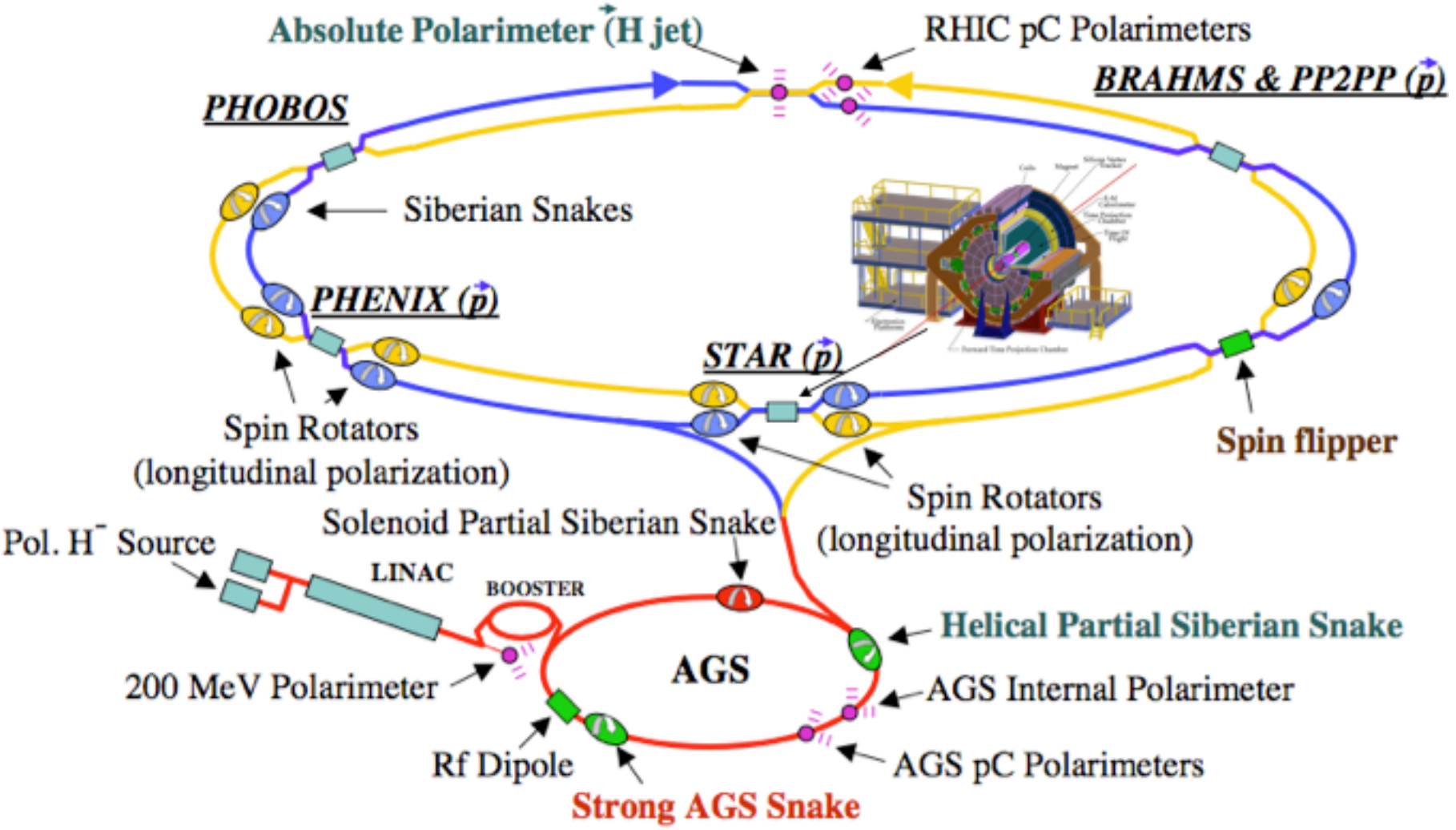
Y. Chen et al, hep-ph/0707.0534

$\bar{\Xi}^{0,+}$ polarization provide sensitivity to $\Delta\bar{s}$, as $\bar{\Lambda}$,

$\bar{\Sigma}^{+,-}$ can provide infomation for $\Delta\bar{u}$ and $\Delta\bar{d}$.

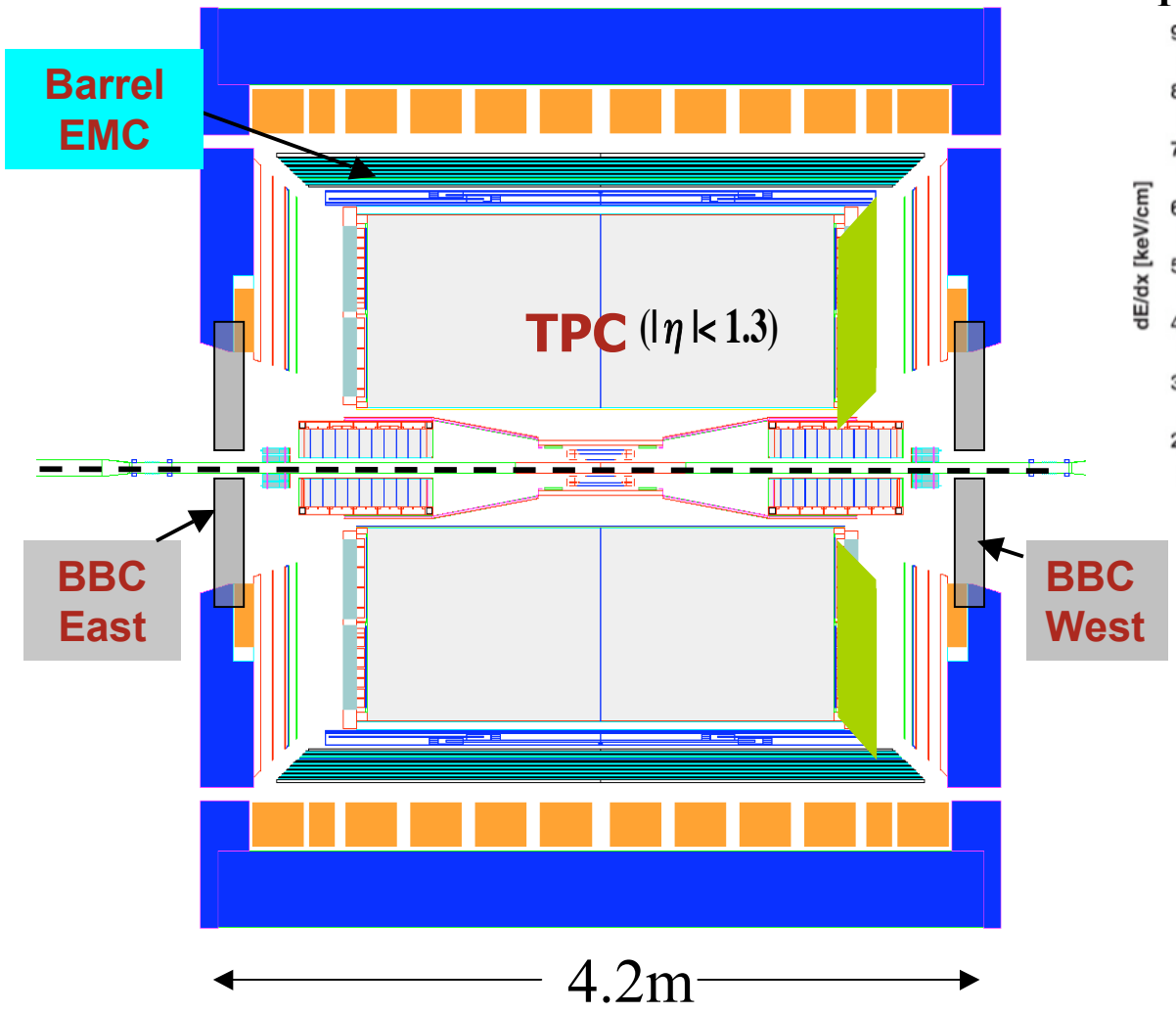
- good opportunity when large amount of data available.

RHIC- also a polarized pp collider

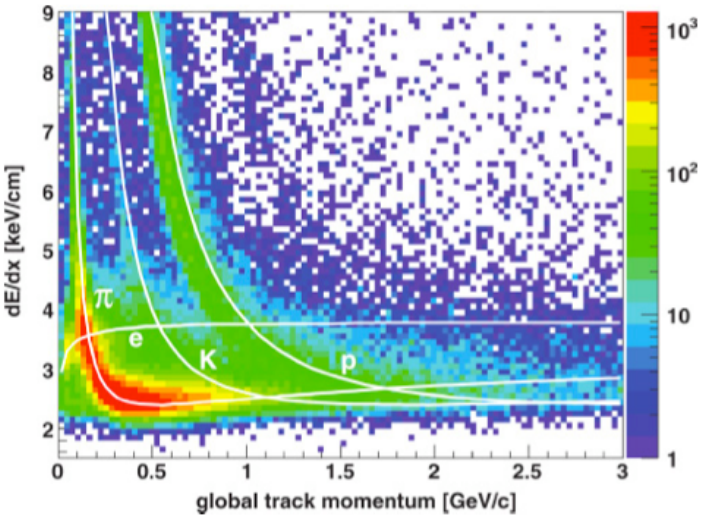


This work: $\sqrt{s}$=200 GeV, ~2 pb^{-1} , Pb~50% (longitudinal), collected in 2005 at STAR

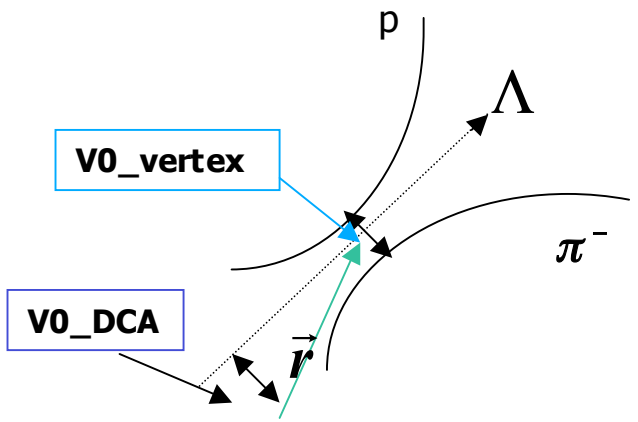
STAR - Solenoid Tracker At RHIC



Time Projection Chamber enables PID



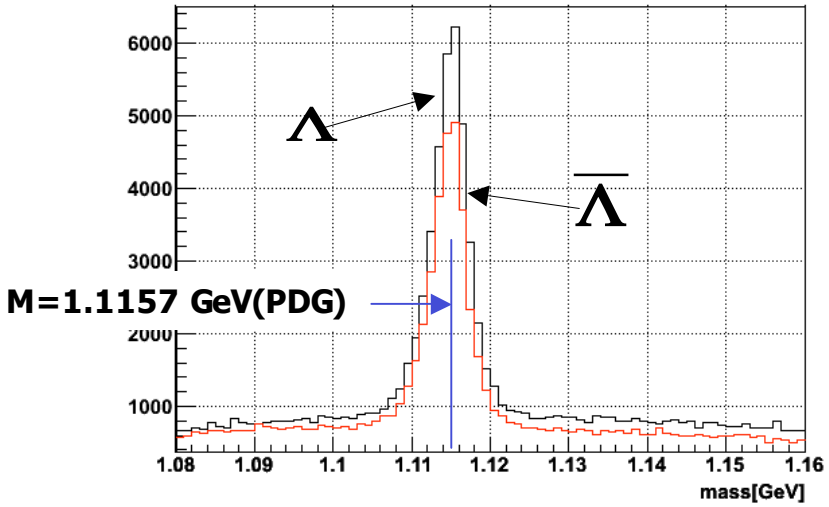
Plus topological reconstruction:

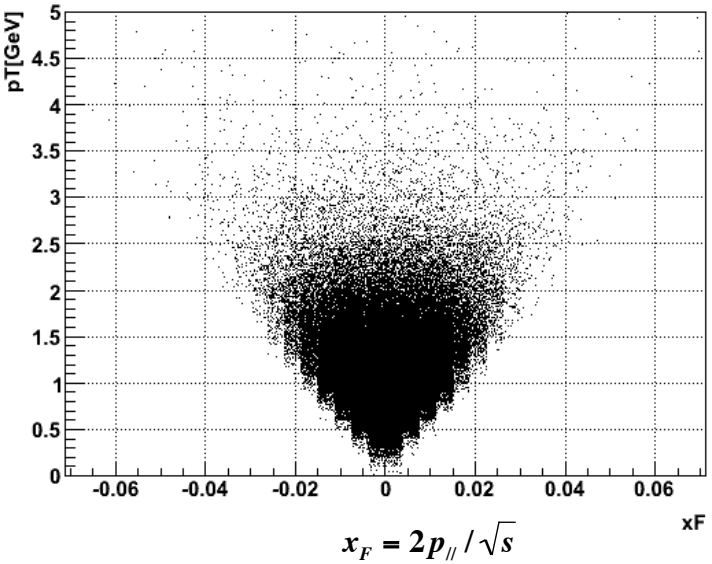


for |η|<~1.3

STAR data - 2005

~3X10^6 events collected with a beam-collision trigger (minimum bias, bandwidth limited),





~ 30X10^3 Λ candidates

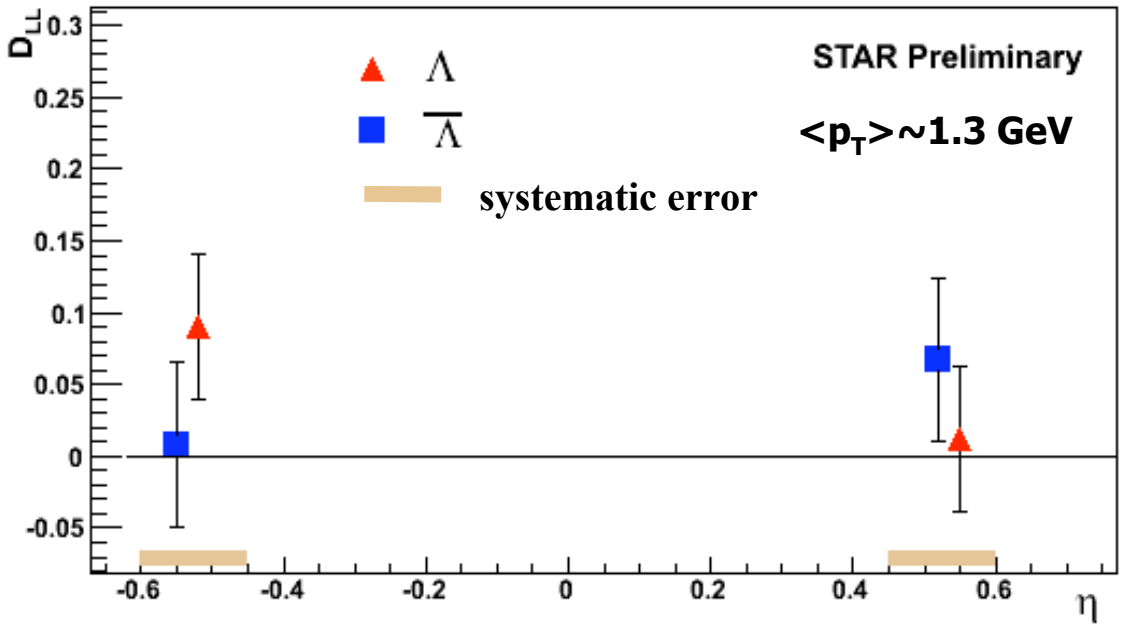
~ 25X10^3 $\overline{\Lambda}$

<p_T>~1.3 GeV

<|x_F|>~0.0075

Results I

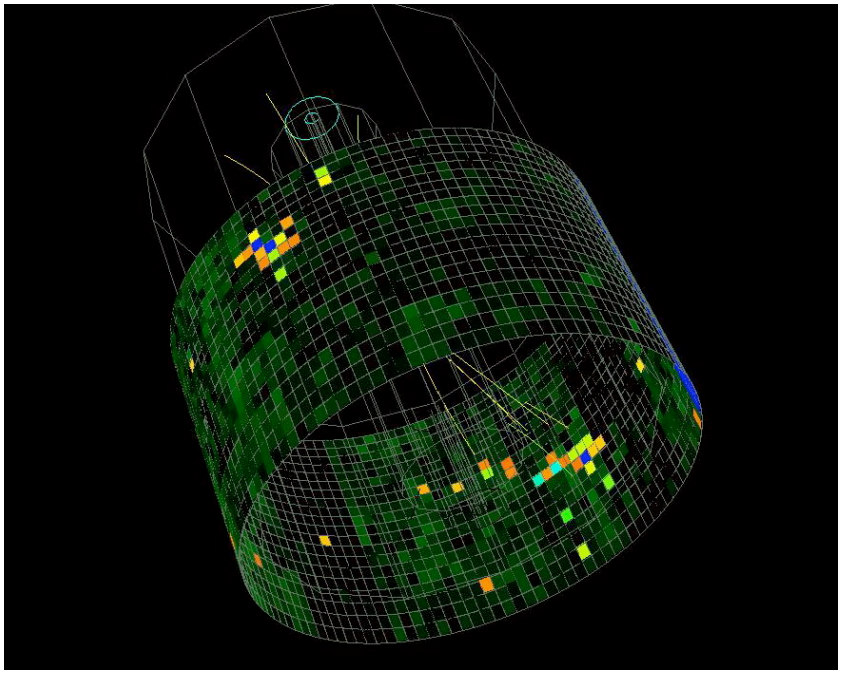
- First D_{LL} results from RHIC:

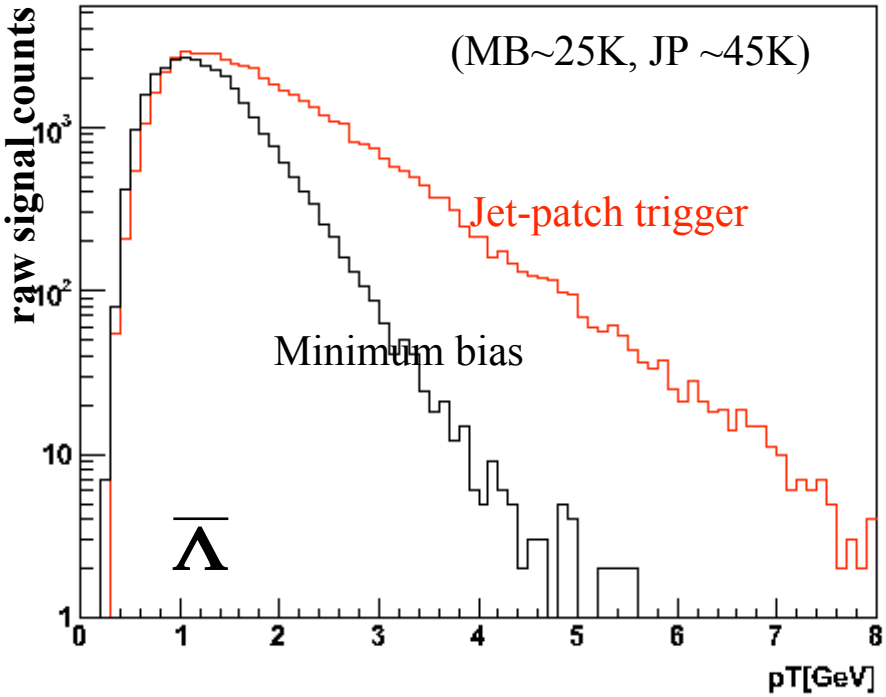


- Statistics and p_T limited,
- Need better precision and higher p_T.

STAR triggered data - 2005

STAR was triggered on energy deposits in jet-patches of the Barrel E.M. Calorimeter,

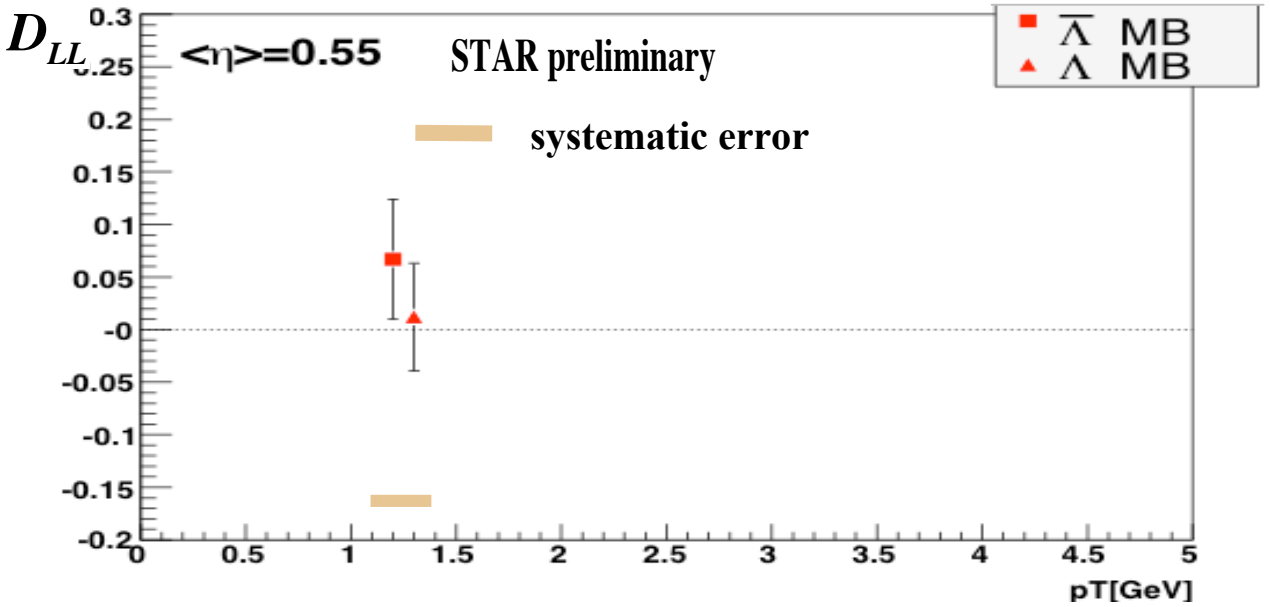




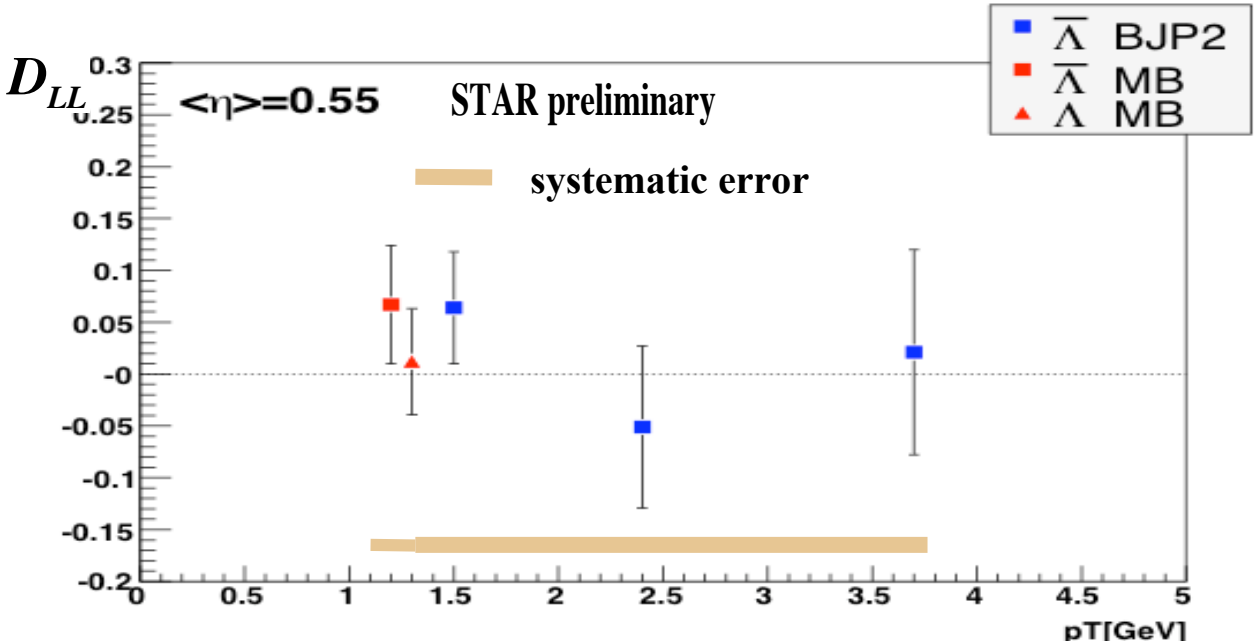
Trigger on high p_T jets --> higher p_T hyperons in jets

Recorded a (biased) sample of Λ and $\overline{\Lambda}$ candidates with considerably higher p_T, although not directly triggered; focus on $\overline{\Lambda}$ here.

Results II


D_{LL}
<η>=0.55
STAR preliminary
systematic error
$\bar{\Lambda}$ MB
Λ MB
0.3
0.25
0.2
0.15
0.1
0.05
-0
-0.05
-0.1
-0.15
-0.2
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
pT[GeV]

Results II


D_{LL}
<η>=0.55
STAR preliminary
systematic error
$\bar{\Lambda}$ BJP2
$\bar{\Lambda}$ MB
Λ MB
0.3
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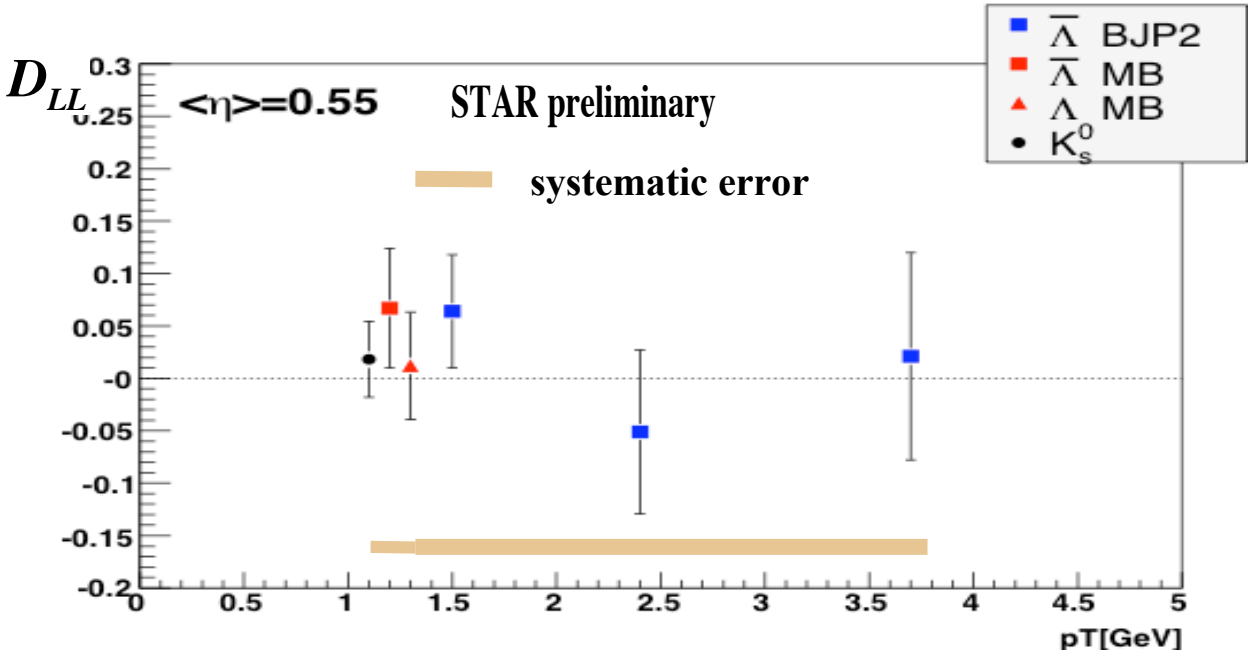
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
pT[GeV]

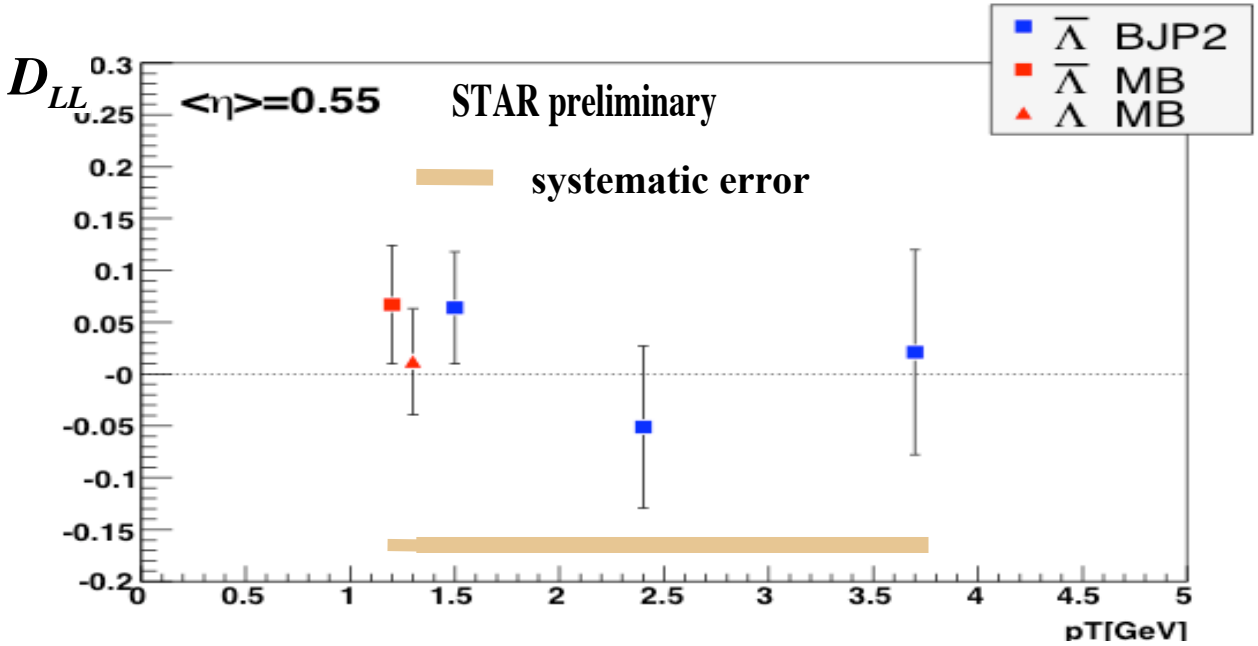
Results II



- Control measurement with spin-0 K_0 shows the expected null-result.
- $\overline{\Lambda}$ systematic uncertainty estimates:
  - 5% scale uncertainty from RHIC beam polarization measurement.
  - 2% from decay-parameter (0.642±0.013).
  - 2% from non-longitudinal beam polarization components at STAR.
  - <0.01 from relative luminosity measurement.
  - <5% background fraction.
  - <4% pile-up effects in TPC.
  - <15% trigger bias estimated from MC simulation.

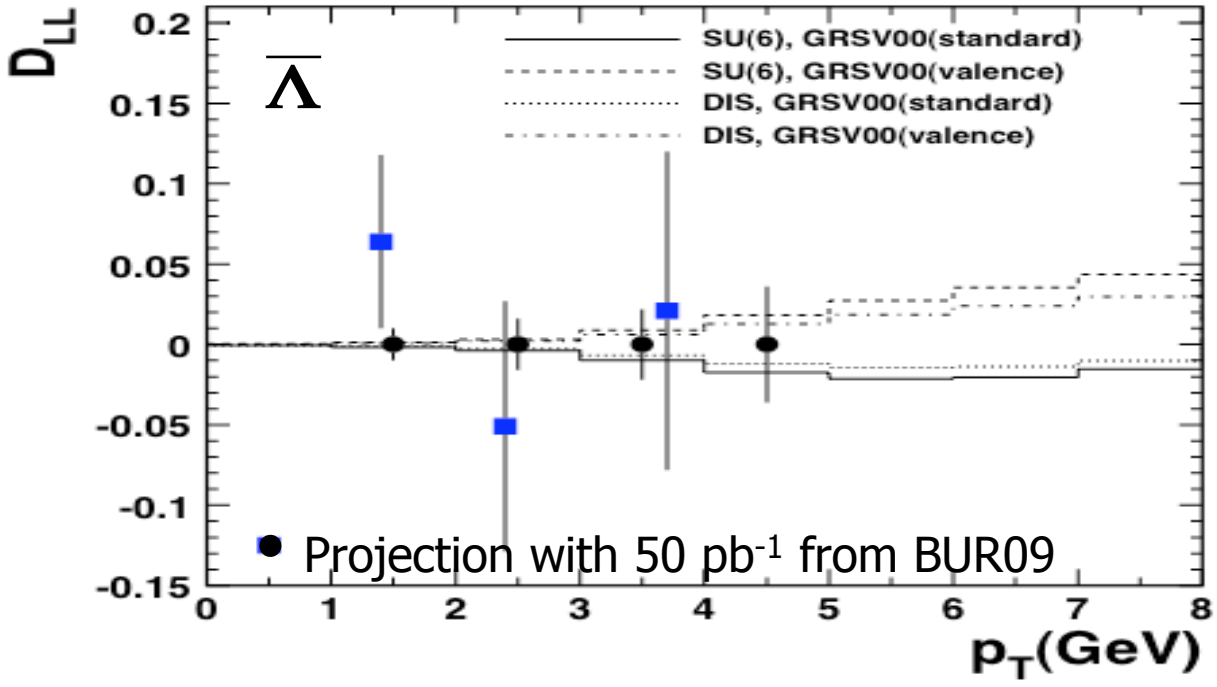
Summary

- Quark spins carry a surprisingly small fraction of the nucleon spin, and in particular the polarization of strange quarks needs further investigation.
- The production of $\Lambda + \overline{\Lambda}$ at RHIC can be described with perturbative QCD,
- Expectations for $\overline{\Lambda}$ spin transfer measurements at RHIC, based on pQCD. show sensitivity to $\Delta\bar{s}$ at high p_T .
- We have performed the first proof-of-principle measurement, using a beam collision trigger, and extended the p_T coverage with a jet trigger.



Outlook

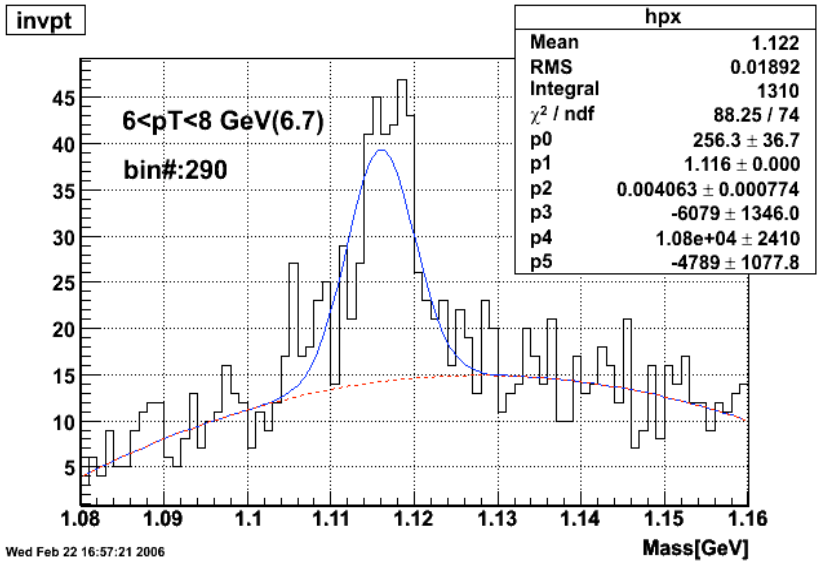
STAR requested data collection in 2009 is a significant step toward the needed precision,

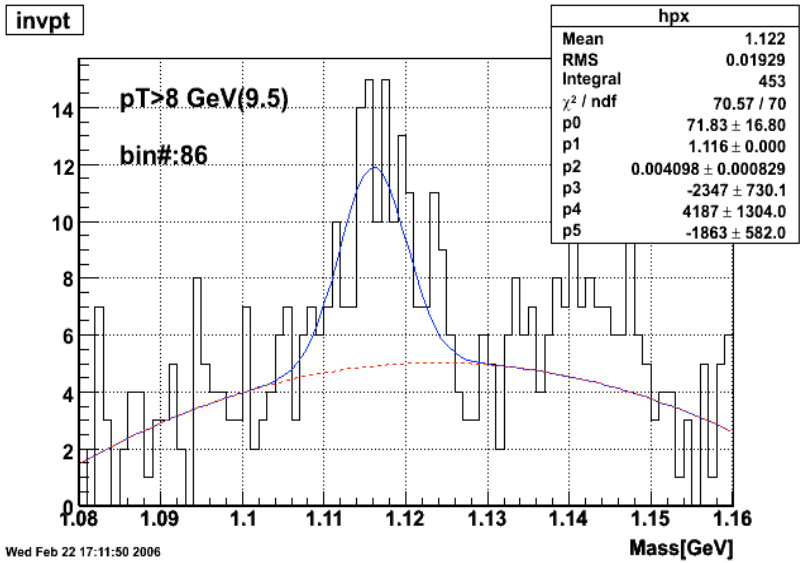


to be further improved in subsequent running periods at 200 and 500 GeV center-of-mass energy,

In addition, we will continue our search for better triggers.

Backup slides

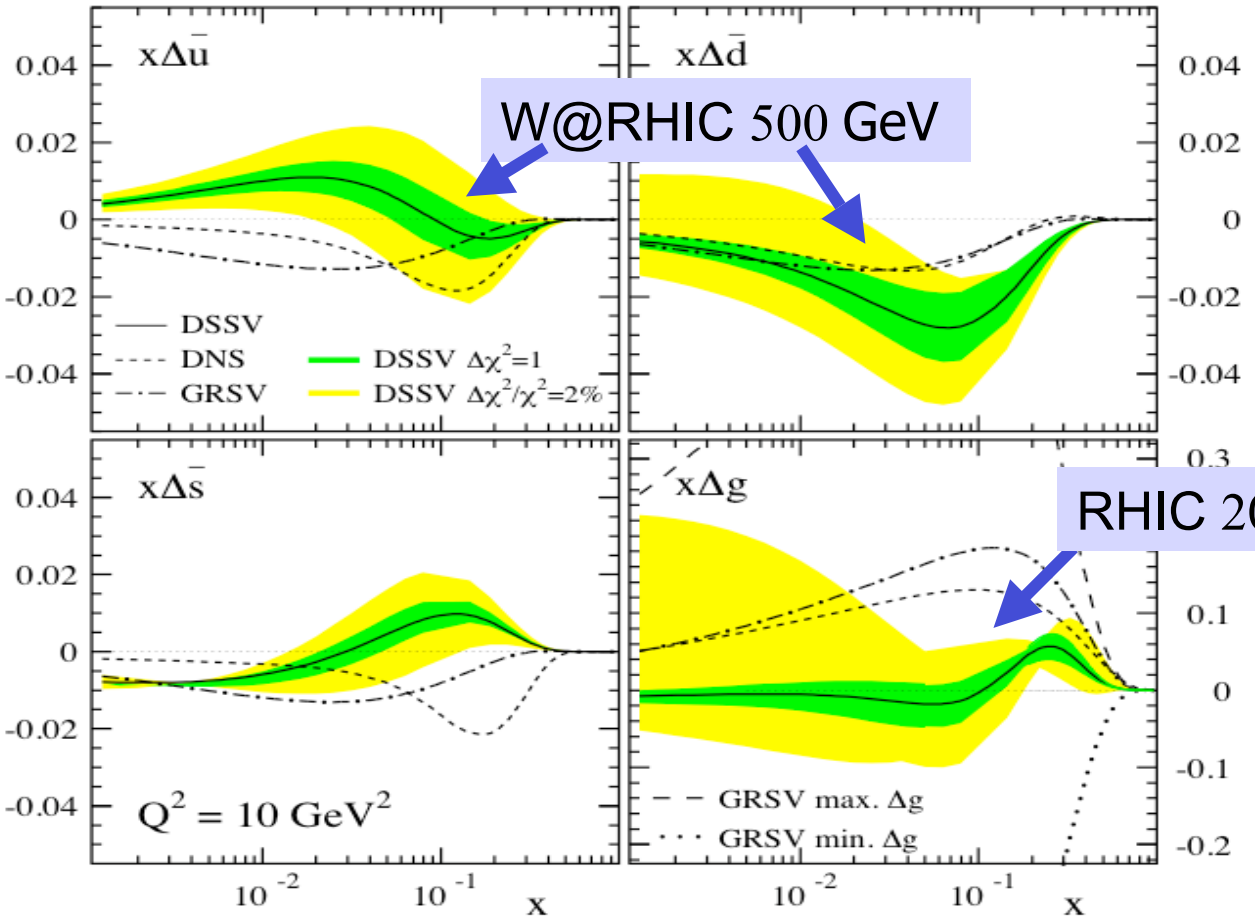




From the most recent global analysis

--fit all the available data in DIS, SDIS and *pp*

D. de Florian et al, arXiv:0804.0422



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$\Delta d + \Delta\bar{d}$	-0.458
$\Delta\bar{u}$	0.036
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$\Delta\bar{s}$	-0.057
Δg	-0.084
$\Delta\Sigma$	0.242

Extraction of D_{LL}

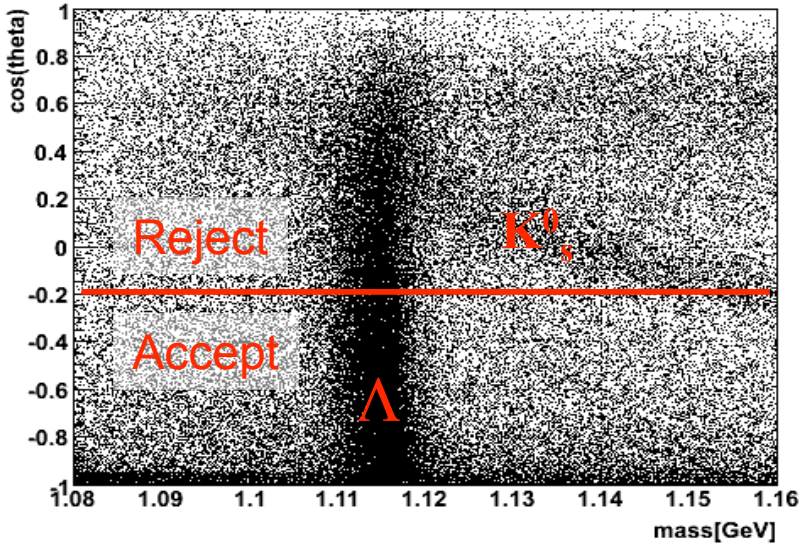
- From the momentum distribution in its weak decay $\Lambda \rightarrow p\pi^-$

$$dN = \frac{N_{tot}}{2} A(\cos\theta^*)(1 + \alpha P_\Lambda \cos\theta^*)$$

Use beam spin configuration and symmetries to cancel the detector acceptance A(cosθ*) in small cosθ^* bin:

$$D_{LL} = \frac{1}{\alpha \cdot P_{beam} < \cos\theta^* >} \cdot \frac{N^+ - RN^-}{N^+ + RN^-}$$

Luminosity ratio R measured with BBC at STAR and beam polarization at RHIC

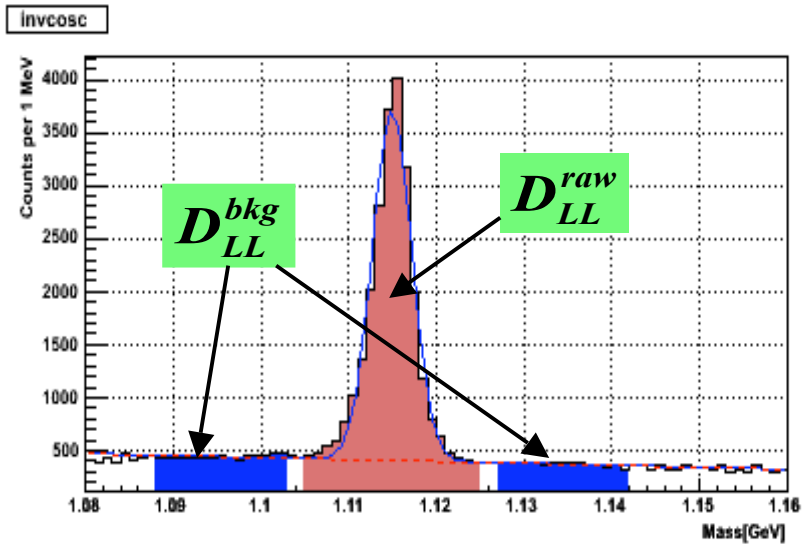


- Restrict cosΘ^*<-0.2 to remove K^0_s bg.

Residual bg. contribution subtracted via

$$D_{LL}^{sig} = \frac{D_{LL}^{raw} - rD_{LL}^{bkg}}{1 - r}$$

r: fraction of background



- Model on the polarized fragmentation function:

$$\frac{\Delta D_q^{\bar{\Lambda}}(z)}{D_q^{\bar{\Lambda}}(z)} \propto \Delta Q$$

G.Gustafson, J.Hakkinen(1993)
C.Boros, Z.T.Liang(1998)

	$\bar{\Lambda}$	
	SU(6)	DIS
$\Delta\bar{U}$	0	-0.17
$\Delta\bar{D}$	0	-0.17
$\Delta\bar{S}$	1	0.62

- Application of model:

$$e^+e^- \rightarrow Z_0 \rightarrow \Lambda/\bar{\Lambda} + X$$

-- data with best precision

(Boros, Liang,PRD'98)